

A STUDY OF
RUTHENIUM 106 AS A BETA SOURCE IN
RADIATION THERAPY

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1951

Thesis
B8295

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IN RADIATION THERAPY

A Thesis
Presented in Partial Fulfillment of the Requirements
for the Degree Master of Science

By

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The Ohio State University

1951

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Thesis
138295

THEORY OF THE EARTH AND ITS HISTORY

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A STUDY OF RUTHENIUM 106 AS A BETA SOURCE
IN RADIATION THERAPY

INTRODUCTION

It is the purpose of this paper to present a study of the properties of the radiations emitted by Ruthenium 106 and its daughters as applied to the therapy of the external lesions of cancer, various warts and moles, and such other surface disturbances of the body as may be responsive to irradiation.

The generally accepted current medical practice is to treat these abnormal conditions by surgery (excision or cauterization), by the use of various chemotherapeutic agents (very limited in number and scope), or by irradiation of the affected area when other methods are not considered practicable. Surgery and, to a lesser degree, chemotherapy are frequently considered impracticable⁽⁶⁾ for a number of reasons:

1. The position of the growth renders surgical approach difficult without high mortality or crippling risk.
2. The growth may be too extensive.
3. Metastases may be present.
4. The poor general health of the patient due to cardio-vascular or renal disease, obesity, or debility from old age.

INTRODUCTION

It is the purpose of this paper to present a study of

the properties of the various tissues of the human body and the functions as applied to the history of the various tissues at present, within their own limits, and with other tissues also.

The generally accepted current medical practice is to

invest these tissues in order to determine their functions in relation to the use of various chemical elements (very limited in number and range) as in the history of the tissues and their other functions and not chemical properties. Current and to a certain extent, the history of the tissues is determined by the history of the tissues.

(*) for a study of the tissues

1. The position of the tissues in the body

2. The position of the tissues in the body

3. The position of the tissues in the body

4. The position of the tissues in the body

5. The position of the tissues in the body

6. The position of the tissues in the body

7. The position of the tissues in the body

8. The position of the tissues in the body

5. The patient may, for his own reasons, refuse surgical treatment.

According to statistics compiled by the Swedish Cancer Association, only one-third of all cancerous conditions coming under medical supervision are suitable for surgery; and, of those who undergo surgery, only one-third ($1/9$ of the total) show other than temporary, short-lived relief. One must also consider all of the noncancerous conditions, many of which are not suitable for surgery. It is, therefore, frequently necessary to employ one or more of the various methods for radiation therapy. Currently, the most commonly employed radiation sources are X-ray machines and radium for gamma and/or beta-ray treatments. Any of these methods involve essentially the same hazards as are found in the deep irradiation therapy of malignant growths which cannot be reached by the short-range beta particles. This is true even of the radium beta ray applicators since the beta-emitting daughters of radium are maintained in equilibrium with those emitting gamma rays, and thus produce a deep irradiation field which is unnecessary in the treatment of surface lesions, and is undesirably detrimental to the normal tissues of the patient and to the health of the attending physician. The successful treatment of any malignant or disfiguring growth by irradiation depends upon the administration of a quantity of radiation sufficient to produce permanent arrest of the growth without causing extensive damage to the underlying normal tissue which is essential to proper repair. Where usable, surface

accept treatment."

According to statistics compiled by the Swedish Cancer

Association, only one-third of all cancerous conditions coming
under medical supervision are suitable for surgery and, of those
who receive surgery, only one-third (1/9 of the total) show signs
of cure. In the majority of cases, the tumor also contains all
of the cancerous conditions, many of which are not suitable
for surgery. It is, therefore, frequently necessary to employ one
or more of the various methods for treating cancer. Currently,
the most commonly employed radiation sources are X-ray machines
and radium for external or intra-cavitary treatment. Any of these
methods involving external or intra-cavitary treatment as are found in the
general literature therapy of malignant growths which cannot be
removed by the operation alone. This is true even of
the radium for external treatment since the ionizing particles
of radium are retained in equilibrium with those emitted from
it, and thus produce a dose of radiation which is unnecessary
in the treatment of cancer lesions, and is unduly detrimental
to the normal tissues of the patient and to the health of the attend-
ing physician. The source for treatment of any malignant neoplasia
which grows in cavities depends upon the characteristics of a
quantity of radiation retained in position for some period of time
without causing extensive damage to the surrounding normal
tissues which is essential to proper results. When radium, radon

irradiation has the distinct added advantage in that no surgical or anaesthetic risks need be taken.

Fortunately, during the treatment of a surface lesion, the X-ray or gamma ray dose received by both the patient and the radiologist is not normally sufficient to induce either the acute or the chronic type of radiation sickness. The patient, having received his treatment, leaves the radiation field and, therefore, discontinues his exposure. This is not true of the attending physician, however, for he must also expose himself during the preliminary preparations for a treatment and again afterward in returning the source used to its place of safe storage (when sources other than X-ray machines are used). In addition, it must be considered that a busy radiologist will expose himself in this same manner many times during a single day, and that this daily exposure is continued throughout the year. The proof that many of these doctors do receive an injurious dose leading to chronic radiation injuries may be seen in the large number of radiologists and dentists who have been compelled to undergo amputation of fingers, and even of hands, in the malformed fingernail structure of others, and in the frequently observed pigmentation changes, leukemias, aplastic anemias, and high incidence of carcinoma observed in pioneer radiologists⁽⁴⁾. It has definitely been shown that chronic exposure to nuclear radiations, even at low dose levels, is carcinogenic⁽⁶⁾.

It is, therefore, essential to develop some new source or sources of mildly penetrating radiation for treatment of these

Illustration has the distinct added advantage of being an original

or essentially original work of art.

Unfortunately, during the treatment of a patient having the

very or more very high tension in both the patient and the relief-

effect is not usually sufficient to induce either the pain or the

character of the relaxing treatment. The patient, being treated

his treatment, leaves the treatment, and, therefore, character-

and the treatment. This is not one of the relaxing treatment,

however, for the patient also usually leaves during the relaxing

treatment for a treatment and again attempts to return to the

source used in the place of the source (when source other than

very machine are used). In addition, it was to be understood that

a very relaxed will usually remain in this state when very

time during a single day, and that this state is usually

throughout the year. The great part of these states is relative

an intention state leading to specific relaxation states may be seen

in the form of relaxation and relaxation who have been con-

cluded to various sources of tension and even to pain, as the

relaxed treatment of the patient, and in the treatment

of the patient, relaxation, relaxation, relaxation, relaxation, and

high tension in various states in various relaxation states.

It has definitely been shown that relaxation is a process of relaxation

relaxation, even as the state is relaxation.

It is, therefore, essential to know the state of the

or source of the relaxation for the purpose of the

surface lesions, which will not include the serious gamma-ray hazard incidental to the use of radium sources for beta particles. Another advantage of employing beta ray sources other than radium derivatives is the elimination of the gas-leak hazard, which is so dangerous in radium work. For this purpose, many investigators have been examining the table of isotopes, particularly those fission products available in relatively large quantities from nuclear reactors, in an effort to find beta-emitting materials with a suitable penetrating power and half-life, with a minimum of electromagnetic radiation. Of the various isotopes investigated to date, the current favorite is the strontium 90-yttrium 90 family, of which the effective beta particle has a maximum energy of 2.2 Mev. However, with appropriate filtering to eliminate the low energy 0.63 Mev particle emitted by Sr 90, the intensity of the radiation field falls to 50% of the surface dose in 0.8 millimeters of tissue⁽¹⁶⁾, as shown in Figure 7. Since the effective penetrating depth in soft tissue of this beta particle is fairly low, and, therefore, only very superficial lesions will be reached by it, it is desirable to find some other beta source which possesses a greater penetrating power, thereby requiring a lower total surface exposure to the lesion to achieve the same therapeutic result. This would provide an appreciable reduction in tissue necrosis and the resultant ulceration and secondary infection, as well as a better cosmetic effect, as the lesion heals.

various factors, which will not include the number of
 bands included in the use of positive evidence for each position.
 Another advantage of applying the test to some other than
 ourselves in the situation of the present study, which is to
 determine in radio work. For this purpose, many investigators have
 been examining the table of factors, particularly those listed
 previous available in relatively large numbers from various
 sources, in an effort to find relationships between them.
 suitable penetrating power and half-life, with a minimum of dis-
 integration radiation. Of the various isotopes investigated to
 date, the current favorite in the medical field is Iodine-131,
 of which the radioactive beta particle has a maximum energy of 0.6
 MeV. However, with appropriate filtering to eliminate the low
 energy 0.6 MeV beta particle and the 0.3 MeV gamma ray, the intensity of the
 radiation field falls to 30% of the unfiltered dose in 0.6 MeV
 range of tissue (16), as shown in Figure 7. Since the radioactive
 penetrating depth is not a function of the beta particle in tissue
 but, and therefore, only very superficial lesions will be produced
 by it, it is desirable to find some other beta source which pro-
 duces a greater penetrating power, thereby requiring a lower
 total surface exposure to the lesion to achieve the same result.
 Iodine-131. This would provide an appropriate reduction in
 tissue necrosis and the resulting fibrosis and secondary infection,
 as well as a better cosmetic result, in the lesion itself.

Since high-energy beta particles impinging on the metallic portions of the applicator holders currently in use produce a rather high Bremsstrahlung flux, it is also desirable to develop holders which will minimize this effect. In addition, the applicators should be designed in such a manner as to provide for easy mounting on the patient without requiring the physician to hold them in place as is the case with the current Sr 90 applicators.

It is with these factors in mind that this study, designed to explore the advantageous physical properties of Ru 106 with a view to the advantageous utilization of them in radiation therapy, was initiated. Included herein are data showing the intensity distribution of the beta field surrounding various Ru 106 sources in tissue equivalent phantoms, information concerning the relative X-ray and gamma ray output when the emitter is electroplated on various plating bases, some information on the physiological effects, as well as methods for measuring the penetration of beta particles in tissue phantoms.

for each mounting on the tablet without producing the slightest
the photographs should be designed in such a manner as to provide
to develop before which all makes the effort. In addition,
require a certain high magnification that it is also desirable
certain position of the resulting picture especially in the
since high-magnification pictures are required in the

[illegible]

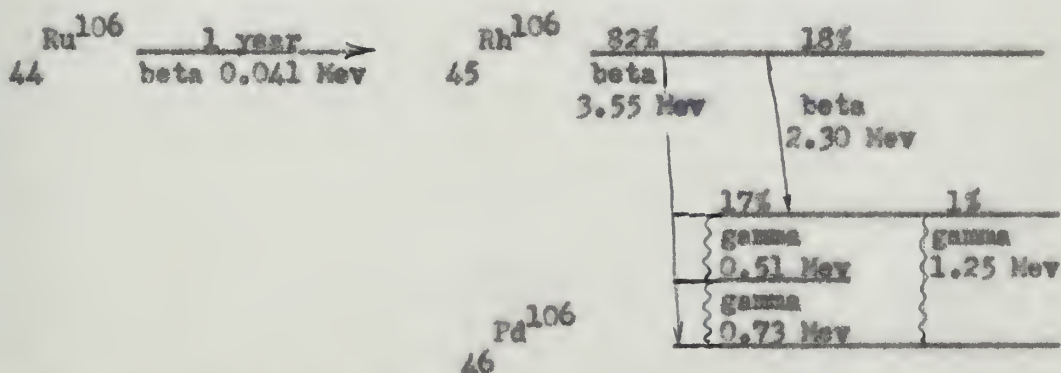
EXPERIMENTATION

Equipment

Ruthenium Sources Employed:

Ru 106 was selected as a possible radiation source for this work due to the conveniently high energy of the beta particle from the daughter element Rh 106, the comparatively constant output incidental to its one year half-life, the extremely low gamma-ray output relative to a radium source of the same beta intensity, and due to the absence of any gas-leakage problem. In addition, ruthenium, unlike strontium(20), does not deposit in the skeletal structure when accidentally ingested.

The decay scheme of the Ru 106 family is(33):



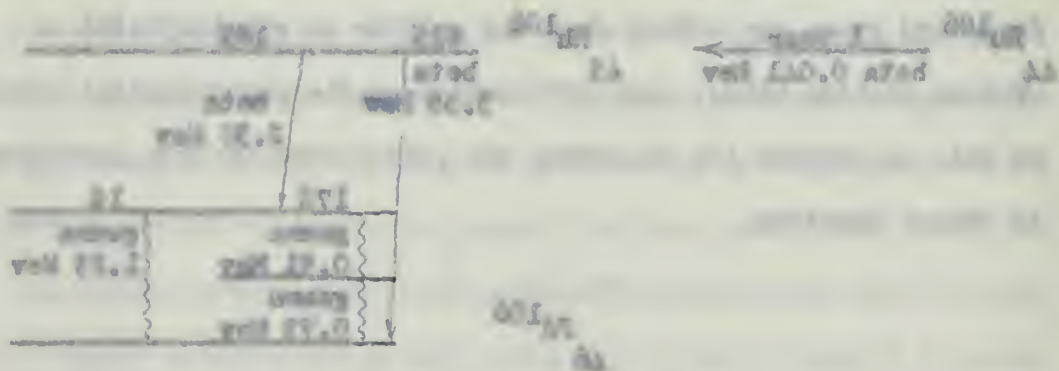
The beta particle from Ru 106 is of very low energy. That portion which is not eliminated by self absorption within the source proper can be readily screened out of the effective radiation field by a thin plastic film which will not appreciably attenuate the desired beta field. This may be readily seen by comparison

EXPERIMENTAL

Equipment

Detector System Details:

The J10 was adjusted as a positive radiation source for this work due to the comparatively high energy of the beta particles from the daughter element Bi 106, the comparatively constant output incidental to its one year half-life, the extremely low gamma-ray output relative to a similar source of the same beta intensity, and due to the absence of any low-energy gamma problem. In addition, collection, unlike strontium-90, does not depend on the physical structure when working with it. The decay scheme of the Bi 106 family is (27):



The beta particles from the J10 are at very low energy. This feature which is not eliminated by self absorption within the source proper and is readily removed out of the effective collection field by a thin plastic film which will not appreciably attenuate the desired beta field. This may be readily seen by comparison

of the range of the two particles. The 3.55-Mev particle has a range of 1.924 gm/sq cm, while the 0.041-Mev particle has a range of less than 0.004 gm/sq cm.

As part of the general aim of this project, an effort was made to determine the relative levels of Bremsstrahlung emission from the various plating bases. For electron energies in the neighborhood of 100 Kev, the efficiency of conversion of electron energy to X-ray energy is directly proportional to the atomic number. That this is not directly applicable to electrons of higher energy is substantiated by experimental work now in progress at the laboratories of the General Electric Company. However, indications are that the final relationship, when developed, will show that the conversion efficiency for these higher energy electrons will be some function of the atomic number of the target material, such that the use of a target of low atomic number will produce less X-ray output than will targets of high atomic number. Gold, copper, and beryllium were selected for study in this aspect.

The specific Ru 106 sources employed in this study were furnished from the Isotopes Division, Oak Ridge National Laboratory. Since ORNL does not specify the exact quantity of material provided in any shipment of this nature, the amounts specified herein are only within the accuracy of the information provided on the shipping papers from ORNL.

Source 1: 2 mC Ru 106 electroplated on a gold disc 0.01 inch thick and 1 inch in diameter. Experimental evidence encountered

of the range of the two variables. The 100-day variable has a
range of 1.000 to 1.000, while the 100-day variable has a range
of 1.000 to 1.000.

is part of the general aim of this project, an effort was
made to determine the relative levels of investigation and
from the various planning teams. For example, examples in the early
history of 100 day, the difficulty of conversion of electric energy
to 100 day energy is directly proportional to the electric energy.
That this is not directly proportional to electric energy
is indicated by experimental work not in progress at the laboratory
of the General Electric Company. However, indications are
that the direct relationship, when developed, will show that the
conversion efficiency for these higher energy electrons will be
very low, of the same order of the lower energy electrons, and
that the use of a variety of low energy sources will produce low
energy output and will require of high energy sources. This energy
and efficiency were selected for study in this report.

The specific in 100 source output is this report
formulated from the Institute of Physics, the National Laboratory,
since this does not require the same quantity of material provided
is an element of this nature, the various specific details are
also of the nature of the information provided in the appendix
of this report.

It is to be noted that the 100 day energy is a value of 1.000

in these tests showed that the Ru 106 was not uniformly plated thereon (Figure 1). Data was not taken from this disc due to the unsatisfactory nature of the emitting surface.

Source 2: 3 mC Ru 106 electroplated on a copper disc 0.01 inch thick and 1 inch in diameter. Again, experimental evidence showed a lack of uniformity in plating the sample on the disc (Figure 2), although this sample was sufficiently satisfactory to permit the taking of data therefrom. It is believed that both samples were probably plated on material which had not received adequate preparation and, possibly, at too high a deposition rate.



Fig. 1. Source 1.
Autoradiograph of source in applicator holder. Note the uneven plating of the Ru 106.

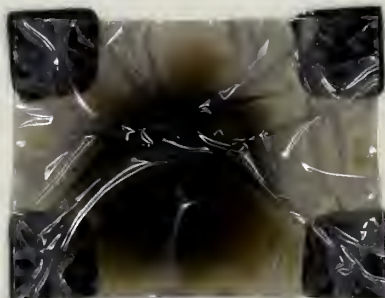


Fig. 2. Source 2.
Autoradiograph of source in applicator holder. Note that the Ru 106 is more evenly plated here.

Source 3: This source has not yet been delivered from ORNL. It has been requested that 3 mC Ru 106 be plated on a beryllium disc 1 cm thick and 1 inch in diameter. Although beryllium is a difficult and hazardous material with which to work⁽²⁶⁾, it was selected as the material with the lowest atomic number with which to carry out these tests satisfactorily. The range of the

in these cases showed that the 100 was not uniformly placed
 between figures 1 & 2, but was not with this also has to
 the distribution of the existing pattern.
 Figure 1: 500 is the designated as a square and
 0.01 inch wide and 1 inch in diameter. Again, approximately
 between about a inch of width in placing the sample on
 the line (Figure 2), although the sample was not placed on
 between to prevent the taking of data therefore. It is believed
 that both samples were properly placed on material which had not
 received chemical preparation and, possibly, at the top a slight
 line also.



Fig. 1. Sample 1. Autograph of sample in
 specimen holder. Note
 the narrow placing of the
 100.
 Fig. 2. Sample 2. Autograph of sample in
 specimen holder. Note that
 the 100 is more evenly
 placed here.

Figure 3: This sample was not well aligned from
 the. It has been reported that 3 ml of 100 was placed on a
 portion line 1 on which and 1 inch in diameter. Although
 section is a 0.01 inch and between material with which is work
 is not aligned on the material with the same strain under 140
 which to carry out these tests satisfactorily. The type of the

3.55 Mev beta particle in beryllium is 11.1 mm. Since this beryllium disc should be covered with about 1 mm of Al as a convenient handling case, essentially all the beta rays from this source will be completely stopped within the source proper. This will eliminate any beta hazard from back radiation to the radiologist who may be called upon to manipulate it, and will also make the applicator a convenient size and weight to be fastened directly to the area to be irradiated. The light-weight feature is highly desirable in that, although surface growths of the type to be treated with this applicator are not normally supplied with neural fibers, pressure on the lesion transferred to the surrounding tissue can cause the patient considerable discomfort.

Electronic Circuits:

The electronic circuit employed in this study is one designed by A. O. Nier⁽³¹⁾ for use in a mass spectrograph, and modified for use as a d.c. amplifier with miniature ionization chambers by D. T. Eggen, who also did the initial construction work on the instrument. Dr. Eggen's modification merely consisted of employing one channel of Dr. Nier's circuit and modifying the filament supply of the amplifier to provide the proper current for half as many tubes in series.

Since the equipment had been in dead storage for some time prior to the beginning of this project and had been rather

7.15 The test position in position 11.1 and 11.2 was this
position should be covered with about 1 m of 11 in a
overhead banding case, necessarily all the test runs from
this source will be completely absorbed within the source region.
There will certainly be some loss from back radiation to the
collimator and may be called upon to manipulate it, and will
also make the application a convenient one and weight to be
transmitted directly to the area to be irradiated. The light-
weight feature is highly desirable in that, although surface
growth of the type to be treated with this application are not
usually applied with enough force, pressure on the device
transmitted to the surrounding tissue can cause the patient
considerable discomfort.

Electron Beam

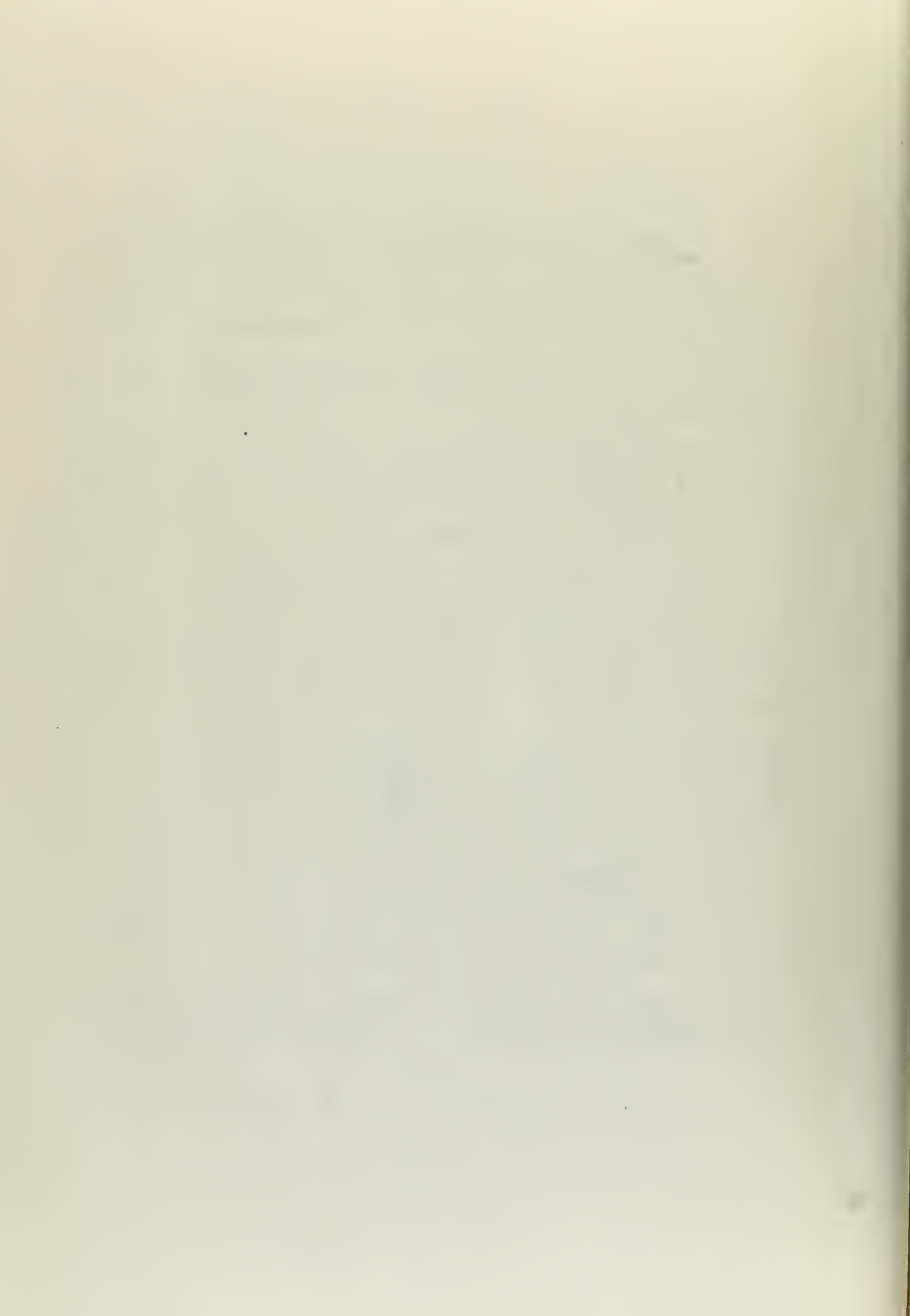
The electron beam is applied in this way to the
patient by a 7.5 mm (11) for use in a beam spectrometer, and
applied for use as a 4.5 mm. applied with minimum deviation
applied by 0.7 mm, and also the initial concentration
used on the instrument. Dr. Taylor's modification merely was
that of applying one element of Dr. Taylor's element and with-
out the filament supply of the amplifier to provide the proper
current for both as well as in series.
Since the experiment had been in hand several for some
time prior to the beginning of this project and had been subject

badly mishandled during that period, it was necessary to rebuild a large portion of the system before it could be placed in operation. In applying this instrument to the work with ruthenium, it was necessary to introduce an additional 100,000 ohm resistor into the feedback and metering circuit in order to desensitize the system to the point where it could properly handle the signal strength obtained.

For the assistance of others who may employ this system, operating voltages are shown on the circuit in Figure 3. Caution must be used to insure that the high voltages are not applied to the preamplifier until its cathode has had at least thirty seconds to warm. It is also advisable to permit the entire electronic system to warm for several minutes to establish the stability required for this work. Shielding is necessary on the cable from the preamplifier to subsequent stages as there is enough cable pickup to make the unshielded system unstable. It is also necessary to establish an electrical connection between the mercury-water system (see discussion of phantom) and the amplifier, since the changing electric field and static charge developed while the mercury is flowing will otherwise drive the meter off scale, requiring several seconds for the system to discharge. For this purpose, it is recommended that the connection be made to the outer electrode of the chamber for the additional reasons discussed under ion chamber windows.

being substituted during that period, it was necessary to maintain
a large portion of the system before it could be placed in opera-
tion. In making this statement to the work with reference, it
was necessary to introduce an additional 100,000 and therefore
into the system and working already in order to discontinue
the system to the point where it would properly handle the amount
already obtained. For the maintenance of others who may wish this system
operating reference are shown in the report in figure 3. Section
one is used to show that the high voltage has not applied to
the transformer until the system has had at least three months
to run. It is also desirable to provide the entire electronic
system to work for several minutes to establish the stability
required for this work. Although it is necessary on the whole from
the perspective to independent stages as there is enough work
going to make the combined system unstable. It is also neces-
sary to establish an electrical connection between the various
water system (and discussion of pumping) and the electrical system
the electronic circuit which will enable charge developed within the
system is flowing will withdraw from the circuit all work.
regarding several months for the system to discharge. For this
purpose, it is recommended that the connection be made to the
other elements of the system for the additional system discussed
under the system which.

Fig. 3a: Power Supply Circuit Diagram



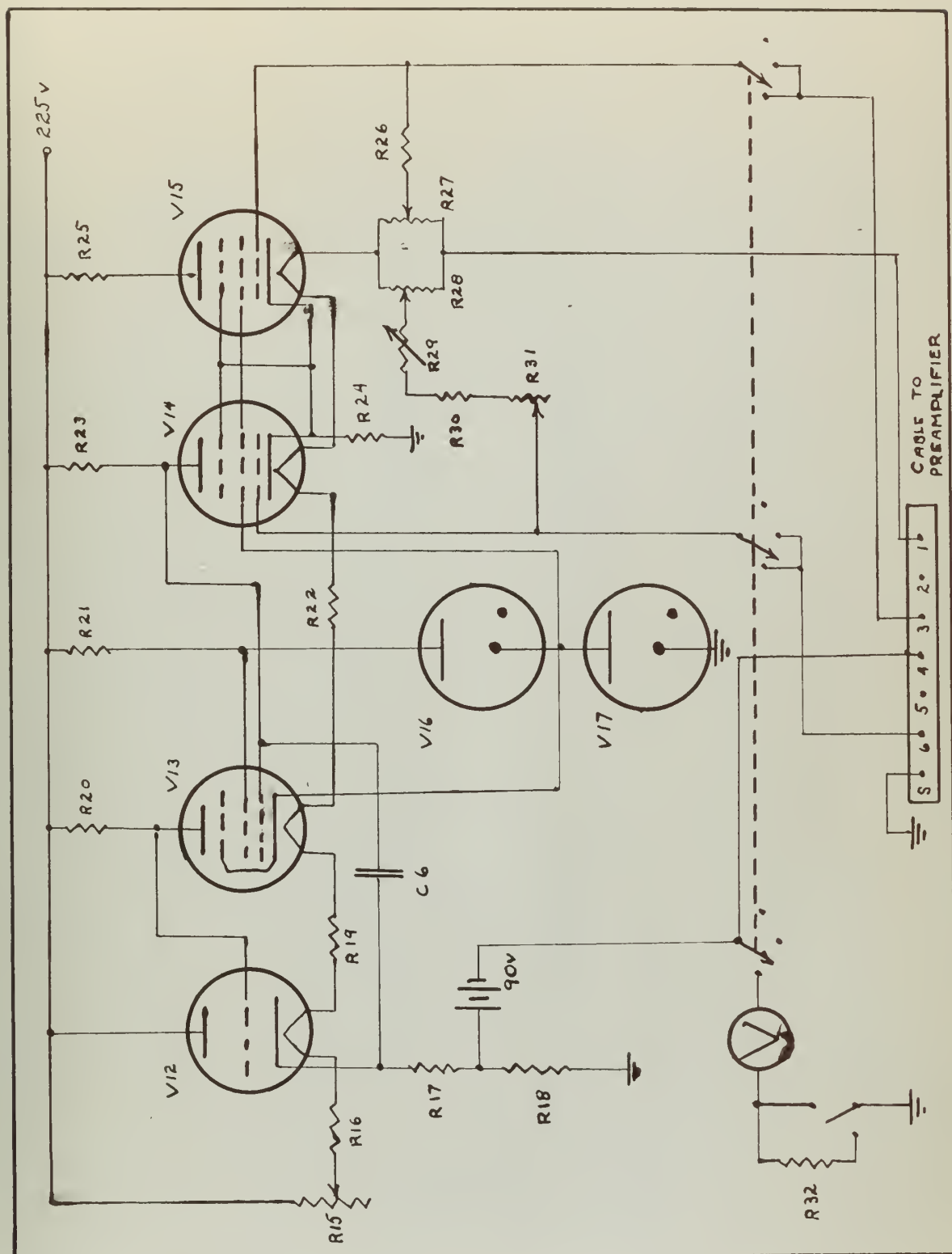


Fig 3b : Amplifier Circuit Diagram

Figure 3d

Values of Circuit Elements

Element	Value	Element	Value
V- 1	5 Y 3	R- 1	5 K
2	5 U 4	2	1 M
3	VR-150	3	1 M
4	VR-150	4	50 K
5	807	5	50 K
6	807	6	3.9 K
7	6 J 5	7	100 K
8	991 neon	8	12.5 K
9	VR-75	9	1 M
10	6 SJ 7	10	1 M
11	6 SJ 7	11	100 K
12	12 J 5	12	25 K
13	12 SJ 7	13	1 M
14	12 SJ 7	14	20 K
15	12 SJ 7	15	500
16	VR-75	16	500
17	VR-75	17	10 K
18	VX-41-A	18	15 K
		19	100
		20	1 M
		21	7.5 K
		22	200
		23	1 M
		24	25 K
		25	1 M
		26	20 K
		27	200
		28	200
		29	20 K
		30	200 K
		31	200 K
		32	100 K
		33	1 x 10 ¹²
		34	5 K
		35	15
		36	25

Summary of Results

Year	1894-95	1893-94	1892-93	1891-92	1890-91	1889-90	1888-89	1887-88	1886-87	1885-86	1884-85	1883-84	1882-83	1881-82	1880-81	1879-80	1878-79	1877-78	1876-77	1875-76	1874-75	1873-74	1872-73	1871-72	1870-71	1869-70	1868-69	1867-68	1866-67	1865-66	1864-65	1863-64	1862-63	1861-62	1860-61	1859-60	1858-59	1857-58	1856-57	1855-56	1854-55	1853-54	1852-53	1851-52	1850-51	1849-50	1848-49	1847-48	1846-47	1845-46	1844-45	1843-44	1842-43	1841-42	1840-41	1839-40	1838-39	1837-38	1836-37	1835-36	1834-35	1833-34	1832-33	1831-32	1830-31	1829-30	1828-29	1827-28	1826-27	1825-26	1824-25	1823-24	1822-23	1821-22	1820-21	1819-20	1818-19	1817-18	1816-17	1815-16	1814-15	1813-14	1812-13	1811-12	1810-11	1809-10	1808-09	1807-08	1806-07	1805-06	1804-05	1803-04	1802-03	1801-02	1800-01	1799-00	1798-99	1797-98	1796-97	1795-96	1794-95	1793-94	1792-93	1791-92	1790-91	1789-90	1788-89	1787-88	1786-87	1785-86	1784-85	1783-84	1782-83	1781-82	1780-81	1779-80	1778-79	1777-78	1776-77	1775-76	1774-75	1773-74	1772-73	1771-72	1770-71	1769-70	1768-69	1767-68	1766-67	1765-66	1764-65	1763-64	1762-63	1761-62	1760-61	1759-60	1758-59	1757-58	1756-57	1755-56	1754-55	1753-54	1752-53	1751-52	1750-51	1749-50	1748-49	1747-48	1746-47	1745-46	1744-45	1743-44	1742-43	1741-42	1740-41	1739-40	1738-39	1737-38	1736-37	1735-36	1734-35	1733-34	1732-33	1731-32	1730-31	1729-30	1728-29	1727-28	1726-27	1725-26	1724-25	1723-24	1722-23	1721-22	1720-21	1719-20	1718-19	1717-18	1716-17	1715-16	1714-15	1713-14	1712-13	1711-12	1710-11	1709-10	1708-09	1707-08	1706-07	1705-06	1704-05	1703-04	1702-03	1701-02	1700-01	1699-00	1698-99	1697-98	1696-97	1695-96	1694-95	1693-94	1692-93	1691-92	1690-91	1689-90	1688-89	1687-88	1686-87	1685-86	1684-85	1683-84	1682-83	1681-82	1680-81	1679-80	1678-79	1677-78	1676-77	1675-76	1674-75	1673-74	1672-73	1671-72	1670-71	1669-70	1668-69	1667-68	1666-67	1665-66	1664-65	1663-64	1662-63	1661-62	1660-61	1659-60	1658-59	1657-58	1656-57	1655-56	1654-55	1653-54	1652-53	1651-52	1650-51	1649-50	1648-49	1647-48	1646-47	1645-46	1644-45	1643-44	1642-43	1641-42	1640-41	1639-40	1638-39	1637-38	1636-37	1635-36	1634-35	1633-34	1632-33	1631-32	1630-31	1629-30	1628-29	1627-28	1626-27	1625-26	1624-25	1623-24	1622-23	1621-22	1620-21	1619-20	1618-19	1617-18	1616-17	1615-16	1614-15	1613-14	1612-13	1611-12	1610-11	1609-10	1608-09	1607-08	1606-07	1605-06	1604-05	1603-04	1602-03	1601-02	1600-01	1599-00	1598-99	1597-98	1596-97	1595-96	1594-95	1593-94	1592-93	1591-92	1590-91	1589-90	1588-89	1587-88	1586-87	1585-86	1584-85	1583-84	1582-83	1581-82	1580-81	1579-80	1578-79	1577-78	1576-77	1575-76	1574-75	1573-74	1572-73	1571-72	1570-71	1569-70	1568-69	1567-68	1566-67	1565-66	1564-65	1563-64	1562-63	1561-62	1560-61	1559-60	1558-59	1557-58	1556-57	1555-56	1554-55	1553-54	1552-53	1551-52	1550-51	1549-50	1548-49	1547-48	1546-47	1545-46	1544-45	1543-44	1542-43	1541-42	1540-41	1539-40	1538-39	1537-38	1536-37	1535-36	1534-35	1533-34	1532-33	1531-32	1530-31	1529-30	1528-29	1527-28	1526-27	1525-26	1524-25	1523-24	1522-23	1521-22	1520-21	1519-20	1518-19	1517-18	1516-17	1515-16	1514-15	1513-14	1512-13	1511-12	1510-11	1509-10	1508-09	1507-08	1506-07	1505-06	1504-05	1503-04	1502-03	1501-02	1500-01	1499-00	1498-99	1497-98	1496-97	1495-96	1494-95	1493-94	1492-93	1491-92	1490-91	1489-90	1488-89	1487-88	1486-87	1485-86	1484-85	1483-84	1482-83	1481-82	1480-81	1479-80	1478-79	1477-78	1476-77	1475-76	1474-75	1473-74	1472-73	1471-72	1470-71	1469-70	1468-69	1467-68	1466-67	1465-66	1464-65	1463-64	1462-63	1461-62	1460-61	1459-60	1458-59	1457-58	1456-57	1455-56	1454-55	1453-54	1452-53	1451-52	1450-51	1449-50	1448-49	1447-48	1446-47	1445-46	1444-45	1443-44	1442-43	1441-42	1440-41	1439-40	1438-39	1437-38	1436-37	1435-36	1434-35	1433-34	1432-33	1431-32	1430-31	1429-30	1428-29	1427-28	1426-27	1425-26	1424-25	1423-24	1422-23	1421-22	1420-21	1419-20	1418-19	1417-18	1416-17	1415-16	1414-15	1413-14	1412-13	1411-12	1410-11	1409-10	1408-09	1407-08	1406-07	1405-06	1404-05	1403-04	1402-03	1401-02	1400-01	1399-00	1398-99	1397-98	1396-97	1395-96	1394-95	1393-94	1392-93	1391-92	1390-91	1389-90	1388-89	1387-88	1386-87	1385-86	1384-85	1383-84	1382-83	1381-82	1380-81	1379-80	1378-79	1377-78	1376-77	1375-76	1374-75	1373-74	1372-73	1371-72	1370-71	1369-70	1368-69	1367-68	1366-67	1365-66	1364-65	1363-64	1362-63	1361-62	1360-61	1359-60	1358-59	1357-58	1356-57	1355-56	1354-55	1353-54	1352-53	1351-52	1350-51	1349-50	1348-49	1347-48	1346-47	1345-46	1344-45	1343-44	1342-43	1341-42	1340-41	1339-40	1338-39	1337-38	1336-37	1335-36	1334-35	1333-34	1332-33	1331-32	1330-31	1329-30	1328-29	1327-28	1326-27	1325-26	1324-25	1323-24	1322-23	1321-22	1320-21	1319-20	1318-19	1317-18	1316-17	1315-16	1314-15	1313-14	1312-13	1311-12	1310-11	1309-10	1308-09	1307-08	1306-07	1305-06	1304-05	1303-04	1302-03	1301-02	1300-01	1299-00	1298-99	1297-98	1296-97	1295-96	1294-95	1293-94	1292-93	1291-92	1290-91	1289-90	1288-89	1287-88	1286-87	1285-86	1284-85	1283-84	1282-83	1281-82	1280-81	1279-80	1278-79	1277-78	1276-77	1275-76	1274-75	1273-74	1272-73	1271-72	1270-71	1269-70	1268-69	1267-68	1266-67	1265-66	1264-65	1263-64	1262-63	1261-62	1260-61	1259-60	1258-59	1257-58	1256-57	1255-56	1254-55	1253-54	1252-53	1251-52	1250-51	1249-50	1248-49	1247-48	1246-47	1245-46	1244-45	1243-44	1242-43	1241-42	1240-41	1239-40	1238-39	1237-38	1236-37	1235-36	1234-35	1233-34	1232-33	1231-32	1230-31	1229-30	1228-29	1227-28	1226-27	1225-26	1224-25	1223-24	1222-23	1221-22	1220-21	1219-20	1218-19	1217-18	1216-17	1215-16	1214-15	1213-14	1212-13	1211-12	1210-11	1209-10	1208-09	1207-08	1206-07	1205-06	1204-05	1203-04	1202-03	1201-02	1200-01	1199-00	1198-99	1197-98	1196-97	1195-96	1194-95	1193-94	1192-93	1191-92	1190-91	1189-90	1188-89	1187-88	1186-87	1185-86	1184-85	1183-84	1182-83	1181-82	1180-81	1179-80	1178-79	1177-78	1176-77	1175-76	1174-75	1173-74	1172-73	1171-72	1170-71	1169-70	1168-69	1167-68	1166-67	1165-66	1164-65	1163-64	1162-63	1161-62	1160-61	1159-60	1158-59	1157-58	1156-57	1155-56	1154-55	1153-54	1152-53	1151-52	1150-51	1149-50	1148-49	1147-48	1146-47	1145-46	1144-45	1143-44	1142-43	1141-42	1140-41	1139-40	1138-39	1137-38	1136-37	1135-36	1134-35	1133-34	1132-33	1131-32	1130-31	1129-30	1128-29	1127-28	1126-27	1125-26	1124-25	1123-24	1122-23	1121-22	1120-21	1119-20	1118-19	1117-18	1116-17	1115-16	1114-15	1113-14	1112-13	1111-12	1110-11	1109-10	1108-09	1107-08	1106-07	1105-06	1104-05	1103-04	1102-03	1101-02	1100-01	1099-00	1098-99	1097-98	1096-97	1095-96	1094-95	1093-94	1092-93	1091-92	1090-91	1089-90	1088-89	1087-88	1086-87	1085-86	1084-85	1083-84	1082-83	1081-82	1080-81	1079-80	1078-79	1077-78	1076-77	1075-76	1074-75	1073-74	1072-73	1071-72	1070-71	1069-70	1068-69	1067-68	1066-67	1065-66	1064-65	1063-64	1062-63	1061-62	1060-61	1059-60	1058-59	1057-58	1056-57	1055-56	1054-55	1053-54	1052-53	1051-52	1050-51	1049-50	1048-49	1047-48	1046-47	1045-46	1044-45	1043-44	1042-43	1041-42	1040-41	1039-40	1038-39	1037-38	1036-37	1035-36	1034-35	1033-34	1032-33	1031-32	1030-31	1029-30	1028-29	1027-28	1026-27	1025-26	1024-25	1023-24	1022-23	1021-22	1020-21	1019-20	1018-19	1017-18	1016-17	1015-16	1014-15	1013-14	1012-13	1011-12	1010-11	1009-10	1008-09	1007-08	1006-07	1005-06	1004-05	1003-04	1002-03	1001-02	1000-01	999-00	998-99	997-98	996-97	995-96	994-95	993-94	992-93	991-92	990-91	989-90	988-89	987-88	986-87	985-86	984-85	983-84	982-83	981-82	980-81	979-80	978-79	977-78	976-77	975-76	974-75	973-74	972-73	971-72	970-71	969-70	968-69	967-68	966-67	965-66	964-65	963-64	962-63	961-62	960-61	959-60	958-59	957-58	956-57	955-56	954-55	953-54	952-53	951-52	950-51	949-50	948-49	947-48	946-47	945-46	944-45	943-44	942-43	941-42	940-41	939-40	938-39	937-38	936-37	935-36	934-35	933-34	932-33	931-32	930-31	929-30	928-29	927-28	926-27	925-26	924-25	923-24	922-23	921-22	920-21	919-20	918-19	917-18	916-17	915-16	914-15	913-14	912-13	911-12	910-11	909-10	908-09	907-08	906-07	905-06	904-05	903-04	902-03	901-02	900-01	899-00	898-99	897-98	896-97	895-96	894-95	893-94	892-93	891-92	890-91	889-90	888-89	887-88	886-87	885-86	884-85	883-84	882-83	881-82	880-81	879-80	878-79	877-78	876-77	875-76	874-75	873-74	872-73	871-72	870-71	869-70	868-69	867-68	866-67	865-66	864-65	863-64	862-63
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Ionization Chamber:

The ionization chamber used as a means of studying the intensity distribution of the beta ray field is shown in Figure 4. It is supported from a plastic disc in the preamplifier housing, and is directly connected into the preamplifier. The chamber has a volume of 0.008 ml. Since 1 r/sec is the equivalent of 2.08×10^9 ion pairs/sec/ml, or one statcoulomb/sec/ml, 1 r for this chamber volume is 7.416×10^{-15} amperes. This would give a signal input to the grid of the preamplifier of 7.416 mv/r/sec, and if one were to use a source of 100 r/sec, the grid swing of 0.7 volts would still be within that allowable for the VX-41-A used.

Various window materials were tried with this chamber, and the chamber was also tried as an open-ended chamber. This latter proved to be unsatisfactory since water vapor from the surface of the phantom shorted the chamber. The most satisfactory window material used was 0.002 inch Zapon. Plastics such as Zapon are so close to the stopping power of water and are so thin that they need not be taken into account in computing the reduction in beam intensity by passage through the water phantom. Aluminum windows were tried and found to be unsatisfactory. Electrolytic action in the phantom tank rapidly produced pinholes in the window, which resulted in the short-circuiting of the chamber. This effect was partially eliminated by placing the entire bath at the same potential as the window, but enough

The investigation showed that as a means of studying

the intensity distribution of the light rays it is found that

Figure 1. It is assumed that a plane wave is incident on the

medium, and is diffracted into the surrounding

medium with a volume of 0.001 m³. When I was in the experiment

of 0.001 m³ for the volume of the medium, the

the total energy was 0.001 m³ of energy. This was

given a signal to the end of the investigation of 0.001

W/m², and it was found that a volume of 0.001 m³ of the

order of 0.001 m³ will be able to absorb the

total energy.

When the medium was placed in the

and the medium was placed in the medium. This

order proved to be the same as the order of the

order of the medium. The order of the

order of the medium was 0.001 m³. This was

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ION CHAMBER

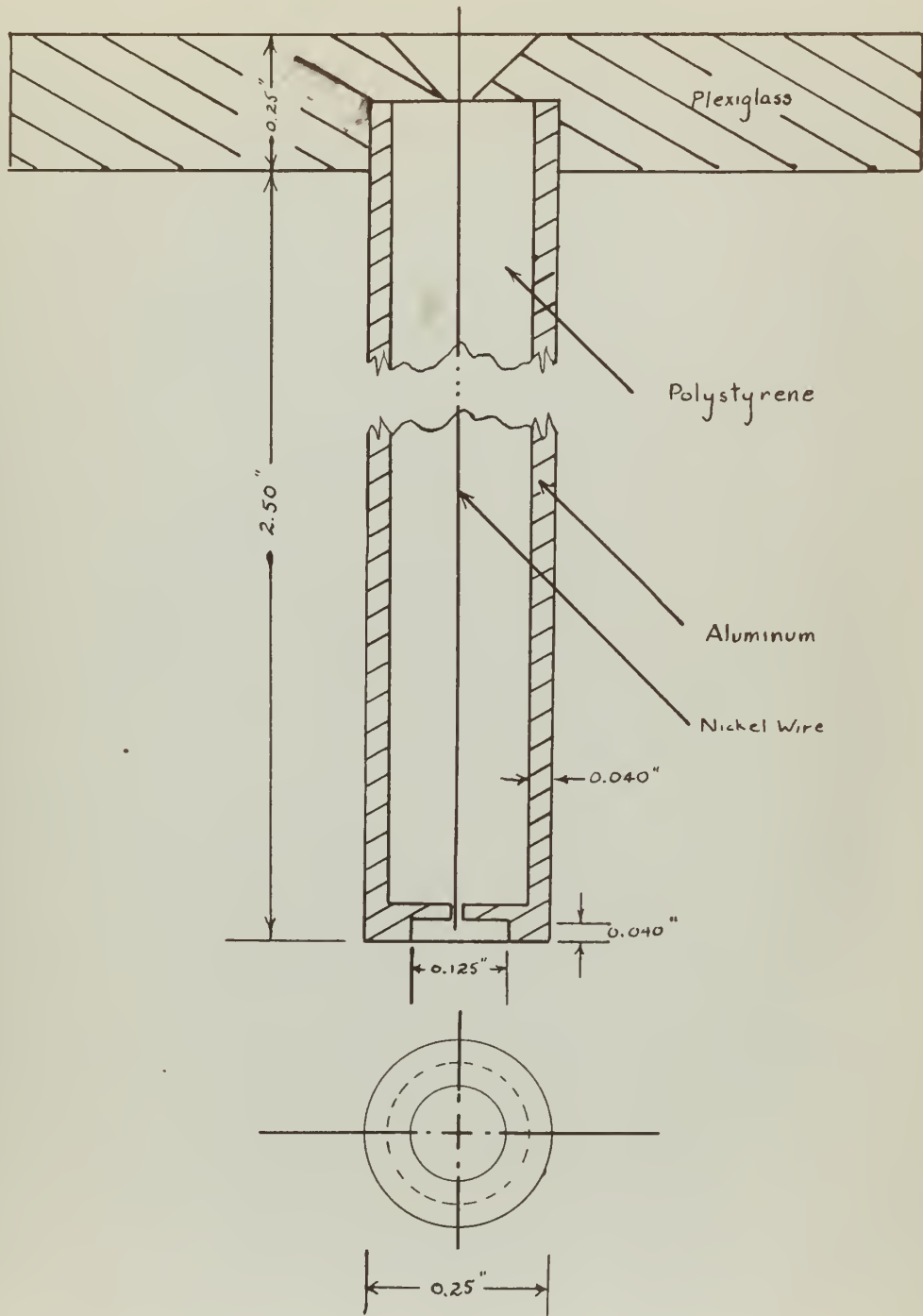


Fig 4

aluminum continued to enter into solution, although much more slowly, to produce punctures in the foil.

Applicator Holder:

The applicator holder used in these tests (Figure 5) was designed to take advantage of the low atomic number of aluminum in the production of α -radiation. The actual structural design was as shown to permit easy and rapid changes from one source to another, as well as to permit the taking of data on one type of beam collimator (the source may be placed in position at either end of the retaining cylinder).

The beryllium-base source may also be used in this holder for comparison purposes, although such a massive construction would not be used in therapy.

Tissue Phantom:

To determine the penetration pattern of the Rh 106 beta particles in tissue, it was necessary to devise some method of simulating the stopping power of soft tissue, since the use of tissue itself is not practicable. Water is commonly used for that purpose (15,16,30,36), and was used here.

In this system, there also had to be included provisions for accurately varying the position relationship between the emitting surface and the measuring device (ion chamber), provision for measuring these variations, and safety measures for protecting

elements combined to make the solution, although some were

likely to produce problems in the field.

ANALYSIS OF THE PROBLEM

The analysis of the problem is shown in Figure 1.

One of the main objectives of the analysis was to identify

the cause of the problem. The analysis showed

that the problem was caused by the fact that the

design was not able to handle the data which was

being fed into it. As well as this, the design of the

one type of data collection (the manual one) was found

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THE PROBLEM

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APPLICATOR HOLDER

All parts are Aluminum except
as indicated

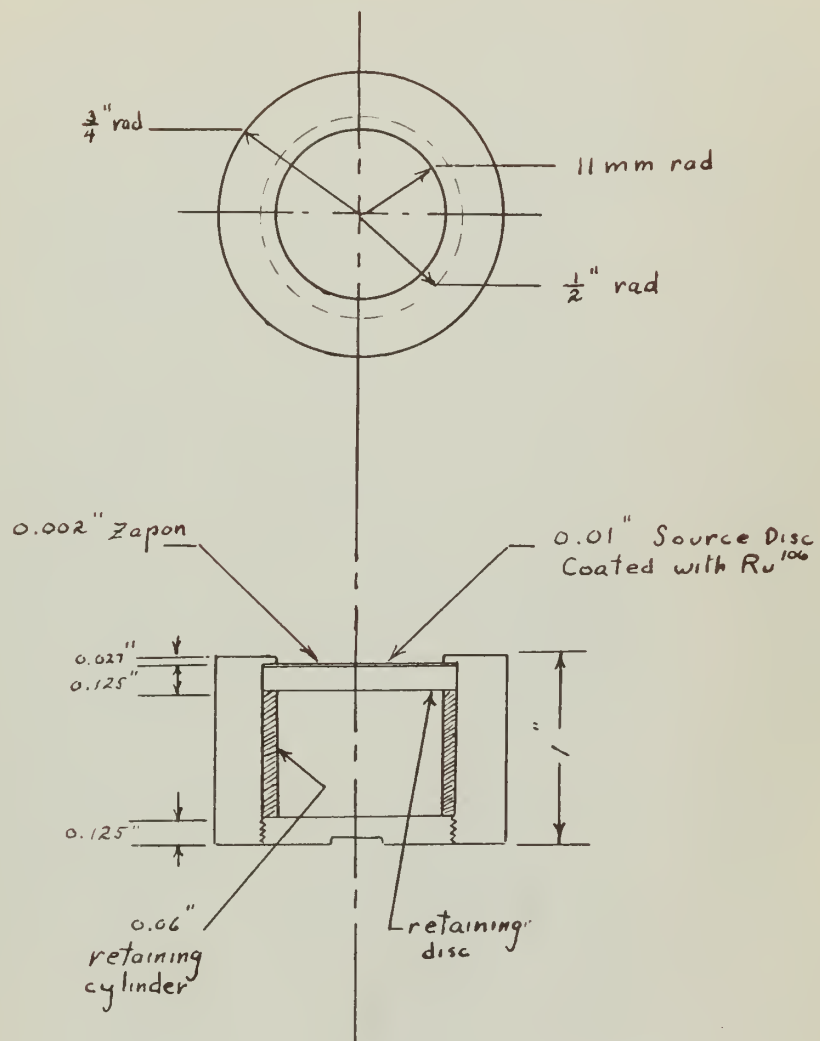


Fig 5
-18-

the operator from the high beta flux involved.

The system as shown in Figure 6 was finally evolved after trial of several variations thereof. Since mechanical systems are vulnerable to the corrosive effects of water and electrolytes, frequently develop leaks, and contain inherent backlash and other mechanical difficulties, it was decided to employ a hydraulic system to drive the moving parts of this mechanism. The tank used was a glass cylinder, 9.56 cm inside diameter, and 10 cm long. This was mounted on a half-inch Plexiglas sheet drilled as shown, and fitted with glass nipples for attachment of the mercury reservoir and a bottom drain for removing mercury without removing water or otherwise disturbing the system. A Plexiglas stage was used upon which the applicator was mounted. This whole assembly, plus the phantom water, was then floated on the mercury surface. The scale on the side of the tank is divided into millimeters, and can, therefore, be read to the nearest 0.1 mm with the aid of a suitable magnifying lens. Thus, by adding or subtracting mercury from the system and reading the position of the Plexiglas stage, it is possible to determine the position of the source relative to the ion chamber. If greater accuracy or more finely spaced readings are desirable, it is merely necessary to compute from the physical dimensions of the tank the volume of mercury which must be added or taken away to provide the desired variation in source-chamber spacing. When employing the volumetric addition of mercury, constant temperature must

The system is based on the following principles:

1. The system is based on the principle of the separation of powers. The executive, legislative, and judicial branches are independent of each other and each is responsible to the people. The executive branch is headed by the Governor, who is elected by the people for a term of four years. The legislative branch is composed of the Senate and the Assembly, both of which are elected by the people for a term of two years. The judicial branch is headed by the Chief Justice, who is elected by the people for a term of eight years. The judges of the Appellate Division and the Supreme Court are also elected by the people for a term of eight years.

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TISSUE PHANTOM

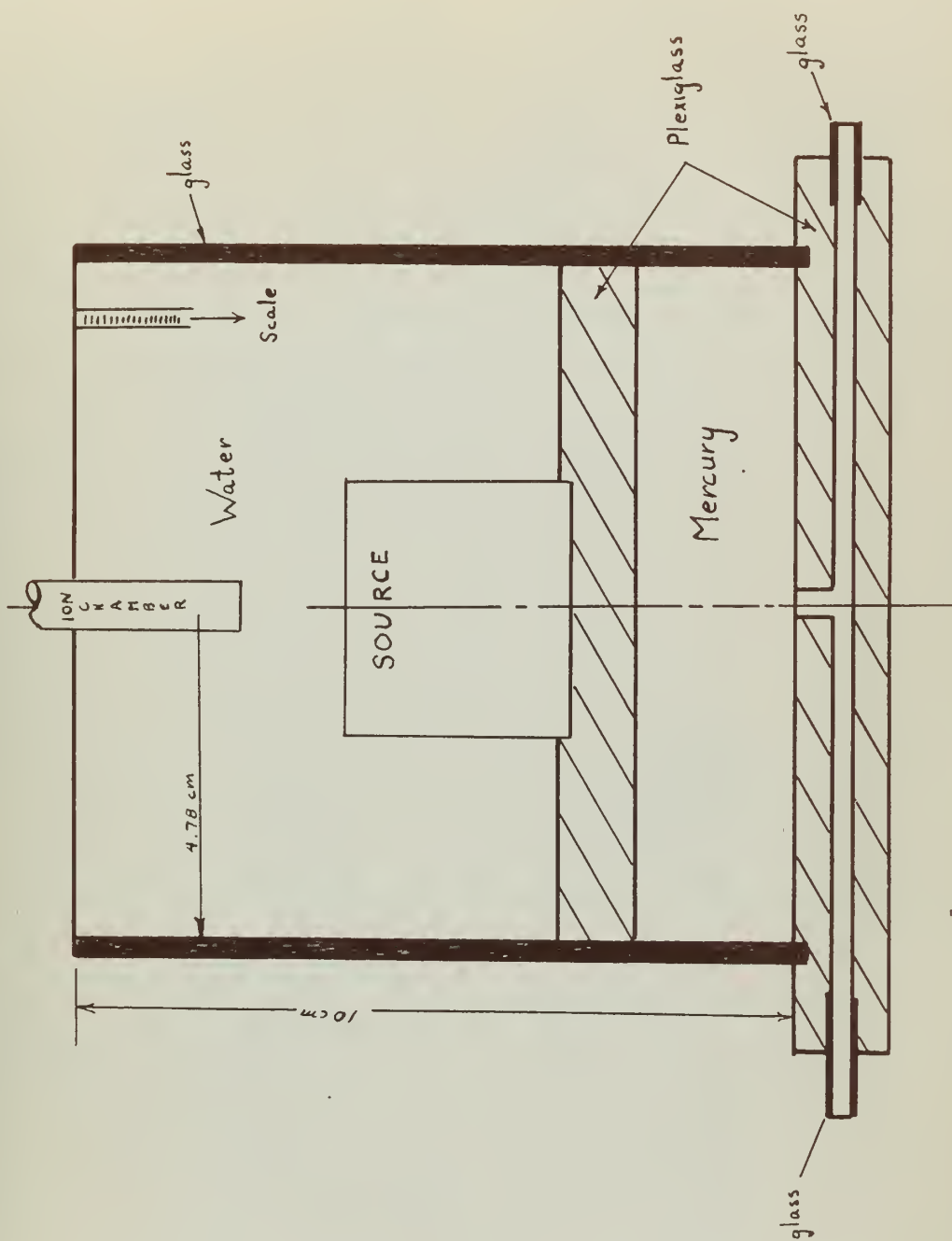


Fig 6
-20-

be maintained to prevent expansion errors. For accuracy requirements within the limits of the tank scale, mercury is introduced from a separatory funnel as a convenient reservoir. Where greater accuracy requirements necessitate the volumetric addition of mercury, a burette is substituted for the funnel. Persons who may employ this system are cautioned that the burette must have a long stopcock, since a short stopcock will be forced out by the pressure of the mercury column in the burette. It is also suggested that all hose connections be clamped and lacquered to prevent spilling mercury. A traversing device for the ion chamber was also provided to facilitate reproducible readings at all points of the applicator surface. A siphon arrangement (not shown) was also provided for convenience in removing water from the tank during operation without exposing the operator to the radiation field. A light was mounted behind the tank to improve visibility. To add contrast between the Flexiglas stage and the water, a blue dye was added to the water. This greatly facilitated measurement and reduced eyestrain.

Incidental Equipment:

Other equipment used for gamma-ray readings, autoradiographs, and the adjustment of the electronic system were of the variety standard in any physics laboratory and merit no special mention or description here.

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Procedure

Beta Ray Penetration Pattern in Water Phantom:

The equipment for this portion of the study was arranged as described. The actual measurement procedure, occasionally modified slightly for special variations, was as follows:

a. Preparation:

1. Balance and zero-set the metering system. This was checked periodically during all runs to insure continued satisfactory operation.

2. Introduce sufficient mercury into the tank to raise the source to a convenient level for the test to be performed. Immerse the ion chamber until contact is made with the surface of the applicator.

b. Measurement:

1. With the chamber in contact with the applicator, record the meter reading. This initial reading is normally made at the center of the applicator and is used as the "100% of Surface Dose" reference. Record, also, the position of the stage.

2. Move the ion chamber to other points on the surface of the applicator and record the meter reading and position data at each point. These lateral points at which readings are made are selected to provide data which will permit accurate determination of the penetration pattern.

THE PROPOSED AMENDMENTS TO THE ACT

The proposed amendments to the Act are intended

to be inserted in the Act as follows:

1. The Act shall be amended so as to read as follows:

2. The Act shall be amended so as to read as follows:

3. The Act shall be amended so as to read as follows:

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18. The Act shall be amended so as to read as follows:

19. The Act shall be amended so as to read as follows:

3. Drain mercury from the tank until the desired source-chamber spacing is obtained. Record the new stage position and the meter readings at each of the lateral positions selected in Step 2.

4. Repeat Step 3 at as many positions as may be necessary to obtain sufficient data to plot a curve of intensity versus distance for each point on the applicator surface. The source-chamber spacing is determined as the difference between the contact position of the stage and the position at any given reading. Distance intervals of 0.2 or 0.3 mm were used up to ranges where the intensity became less than 70% of the surface intensity and where pattern fringes were being examined. This was done to locate the knee of the curve accurately (Figure 7). Greater intervals are permissible thereafter.

5. For each reading obtained in Steps 2-4, compute the percentage of the contact reading, using as reference the reading obtained in Step 1. From these data, plot isodose patterns for each source employed (i.e., Figure 8).

Autoradiographs:

Autoradiographs were introduced into this study to provide the reader with visual confirmation of some of the information determined during the penetration measurements in the tissue phantom.

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As was mentioned previously, the nonuniformity of source plating is demonstrated by Figures 1 and 2. Additional autoradiographs were prepared to substantiate the isodose patterns obtained by electronic measurement. These are included in the data section, along with photodensitometer readings obtained therefrom. These were prepared by stacking film to a depth equivalent to the maximum range of the beta particles and applying the source to the top of that stack for the indicated period, or by mounting the film vertically between paraffin blocks and applying the source to the edge of the film. Each film layer with emulsion was measured to have an average thickness of 0.223 mm and a density of 1.41 gm/cc. Thus, each 0.71 mm of film has an equivalent stopping power of 1 mm of tissue or water. Figure 7 demonstrates the correlation between the densitometric data and the electronic data along the axis of the applicator. Since film emulsions undergo a saturation effect at high intensities⁽⁴⁰⁾, proper correlation at close ranges is difficult to accomplish.

Exposures are indicated with each autoradiograph. Du Pont Type 508 X-ray film was used, and was developed according to the manufacturer's specifications (4 minutes in Du Pont X-ray Developer; 10 minutes in Kodak X-ray Fixer; 68 degrees F.).

Biological Effects:

The information obtained in the brief biological test done in conjunction with this study cannot be considered adequate.

[illegible]

Volume 128, December 1995

The information obtained in the field laboratory was

The test was merely performed to obtain an indication of the nature of the biological reaction to a Ru 106 source.

Source 2 was taped to the shaved back of a male rabbit for a period of 15 hours and 40 minutes, for a total surface dose of 23,900 rep. The rabbit was then observed periodically to determine any biological effects.

Data and Computations

Preparation of a Therapeutic Applicator:

To prepare a therapeutic applicator which will provide a dose rate suitable for clinical use, the physician's requirements must be considered. Each tumor type possesses its own minimum lethal dose which must be applied to insure growth (6,17,21). condition of the _____ periods of treatment. In addition, evidence has been presented which purports to show a relationship between the effectiveness of the total dose and the rate at which it is applied⁽⁶⁾. It is the function of the physician to correlate these factors and select the optimum total dose and optimum dose rate for a particular pathological condition. This paper does not attempt to do this for him.

Included herein are the calculations to be used to determine the activity for a specific treatment based upon

The first two series presented to us in an illustration of the nature
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the desired total dose and the rate at which it is to be administered.

Rh 106 has two decay paths for each of which separate calculation must be made to determine the actual energy transferred to an irradiated area.

Assuming no Bremsstrahlung to be present (introduced later), the rate at which energy is emitted from any beta source is:

$$\text{energy/sec} = (\text{number of beta particles emitted/sec}) \\ (\text{average energy per particle}).$$

Eq 1 $\text{ergs/sec} = kNEM$ where M = number of mC present

$$N = \text{number of particles emitted per mC}$$

$$= 3.7 \times 10^7$$

$$k = \text{conversion factor from Mev to ergs}$$

$$= 1.6 \times 10^{-6} \text{ ergs/Mev}$$

$$E = \text{average energy per particle (Mev)}$$

To obtain the dose rate in any medium in rep/sec, one must use the rep as defined: 1 rep = 95 ergs absorbed per gram of absorbent tissue. The mass of absorbent in any material is:

Eq 2 $\text{gms} = dAR$ where d = density

$$A = \text{area of surface irradiated}$$

$$R = \text{range of particle of average energy } E$$

Division of Eq 1 by Eq 2 then gives the dose rate of the source material as:

The first part of the paper is devoted to the

introduction.

The second part is devoted to the

description of the model and the

results of the calculations.

The third part is devoted to the

discussion of the results and the

conclusions.

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The fourth part is devoted to the

discussion of the results and the

conclusions.

The fifth part is devoted to the

description of the model and the

Eq 3 rep/sec/gm of tissue = $kNEMq/dAR$ where q = conversion factor
 from ergs to rep
 as defined above
 = $1/95$

Using the density of tissue as unity and assuming, temporarily, 100% geometry, substitution of the appropriate conversion factors into Eq 3 gives:

$$\begin{aligned} \text{rep/sec} &= \frac{(3.7 \times 10^7)(1.6 \times 10^{-6})}{95} \cdot \frac{ME}{AR} \\ &= 0.623 \frac{ME}{AR} \end{aligned}$$

Eq 4

Application of Eq 4 to a Sr 90 applicator produced and calibrated by Tracerlab, Inc., gives values comparable to those obtained by the calibration measurements, within a suitable geometric correction. This applicator contains approximately 25 mC of Sr 90, maximum beta energy of 2.2 Mev, and was measured by the manufacturer to provide 28.1 rep/sec at the surface.

The following equation⁽²⁷⁾ permits calculation of the average energy per beta particle:

Eq 5 $n = E/\bar{E}_{max} = 0.33(1 - \frac{Z}{43}^{1/2})(1 - \frac{E_{max}}{4}^{1/2})$

where n = the ratio of the average beta particle energy to the maximum beta particle energy.

For Sr 90, the average energy is therefore:

$$\begin{aligned} \bar{E} &= n E_{max} = (2.2)(0.33)(1 - \frac{38}{43}^{1/2})(1 - \frac{2.2}{4}^{1/2}) \\ &= 0.853 \text{ Mev} \end{aligned}$$

Employing this average energy in Eq 4, the Sr 90 applicator in question having a diameter of 7.7 mm, the dose ratio is:

$$\text{rep/sec} = \frac{0.623 (0.853)(25)}{0.330 \left(\frac{11}{4} 7.7^2 \right)} = 86.5 \text{ rep/sec}$$

To obtain the calibrated value of 28.1 rep/sec, an adjustment factor of 32.5% must be applied to account for losses due to applicator geometry and to account for conversion of beta particle energy to Bremsstrahlung. This correction would seem to be of the proper magnitude based on the limited available information on the internal construction of this Sr 90 applicator, and allowing for the approximation error in the 25 mC value.

Similar calculations for Rh 106 show the average energies of the two beta particles to be:

$$\bar{E} = 1.45 \text{ Mev for } E_m = 3.55 \text{ Mev}$$

$$\bar{E} = 0.88 \text{ Mev for } E_m = 2.30 \text{ Mev}$$

Application of these average energies to Eq 4, with proper allowance for the 82%-18% relationship between the two decay paths, and using unit area for the source, shows:

$$\text{rep/sec} = \frac{0.623}{A} \left(\frac{g\bar{E}}{R} \right)_1 + \frac{0.623}{A} \left(\frac{g\bar{E}}{R} \right)_2 \text{ for 1 mC}$$

where subscript 1 pertains to the 82% decay path, and

2 pertains to the 18% decay path

g = fraction of transitions by the selected path

The range (cm of tissue) for the 1.45 Mev particle is 0.645 cm, and for the 0.88 Mev particle is 0.344 cm.

Substitution of the given values of g , \bar{E} , and R , and assuming unit area for convenience, gives:

$$\text{variance} = \frac{0.140(0.140+1)}{0.140(0.140+1)} = 0.140$$

To obtain the adjusted value of 0.140, an adjustment factor of 0.140 must be applied to account for the fact that the observed variance is in excess of the expected variance. This adjustment will result in the observed variance being equal to the expected variance. The adjustment factor is calculated as follows: $\text{adjusted variance} = \text{observed variance} \times \text{adjustment factor}$. The adjustment factor is calculated as follows: $\text{adjustment factor} = \frac{\text{observed variance}}{\text{expected variance}}$. The expected variance is calculated as follows: $\text{expected variance} = \frac{1}{n} \sum_{i=1}^n x_i^2 - \left(\frac{1}{n} \sum_{i=1}^n x_i \right)^2$. The observed variance is calculated as follows: $\text{observed variance} = \frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2$. The adjustment factor is calculated as follows: $\text{adjustment factor} = \frac{0.140}{0.140} = 1.0$. The adjusted variance is calculated as follows: $\text{adjusted variance} = 0.140 \times 1.0 = 0.140$.

of the two particles is 1.0

$$\bar{E} = 1.41 \text{ eV for } E_p = 1.50 \text{ eV}$$

$$\bar{E} = 0.85 \text{ eV for } E_p = 1.50 \text{ eV}$$

Application of these average energies to the proper formulas for the 50-50 relationship between the two decay rates, and using only one for the lower, shows

$$\text{variance} = \frac{0.140}{2} + \frac{0.140}{2} = 0.140$$

which corresponds to the decay rate, and

$$E = \text{function of } E_p \text{ and } E_n$$

$$E = \text{function of } E_p \text{ and } E_n$$

The average (or mean) for the 100 new particles is

$$0.85 \text{ eV, and for the 0.85 new particles is 0.85 eV.}$$

Calculation of the average values of E_p and E_n and

showing that the two particles, given

$$\text{rep/sec} = \frac{0.623(1.45)(0.82)}{0.645} + \frac{0.623(0.88)(0.18)}{0.344}$$

$$= 1.429 \text{ for } 1 \text{ mC Rh } 106 \text{ on } 1 \text{ sq cm of surface}$$

The test applicator employed herein has a geometry factor of approximately 50% when reflection from the plating base and radiative losses are taken into account. Thus, for each mC/cm² exposed in this system, 0.715 rep/sec enter the area to be irradiated. This is not true in the present practice, since the nonuniformity of the plated surface has already been demonstrated, and the inaccuracies of the ORNL shipping data have been mentioned. Assume 3 mC to be plated uniformly on a Cu disc 1 inch in diameter. Since a 1/8 inch lip covers a portion of the emitting surface, only 56.3% of the emitter is exposed, leaving 1.69 mC effective in creating the beta field. Applying the geometric corrections, this applicator has 0.593 mC/cm², and therefore, supplies (0.593)(0.715) = 0.424 rep/sec/cm² to the irradiated surface.

In the preparation of a practical therapeutic applicator, it is desirable that a minimum of the active emitter be masked by the supporting structure. This can be accomplished by reduction of the width of the supporting lip and/or by masking the area, which is to be covered by the supporting structure, such that no active deposit is made in this region during electroplating.

In the preceding discussion, the production of Bremsstrahlung was omitted in order not to detract from the discussion at that time. Since this process accounts for an appreciable

portion of the electromagnetic radiation in a problem of this sort, and, therefore, is a major contribution to the radiation hazard of high energy beta ray sources, it must be taken into consideration.

In the introductory remarks, it was noted that the true efficiency of conversion of electron energy to X-radiation is probably not an exact linear function of the atomic number. However, since such a true relationship is not yet available, the direct proportionality approach will be employed for the purposes of this discussion. The following equation⁽²⁹⁾ will be used:

Eq. 6 $n = bE Z/1600 mc^2$ where:

n = the portion of the energy converted
to Bremsstrahlung

bE = the average energy for a given beta
ray spectrum

mc^2 = the rest mass of the electron
= 0.00055 mu = 0.512 Mev

Consider only the active disc without any applicator holder, such that the Bremsstrahlung emission is due almost entirely to electrons impinging on the plating base. Over all of the beta energies from Rh 106, the average is 1.35 Mev; therefore, this case, $n = 1.65 \times 10^{-3}Z$. Values of n for the materials in this project are included in the tables:

portion of the electrostatic field is a function of the
 size, and position, of a surface relative to the volume
 of high energy ions in contact, it must be taken into
 consideration.

In the following section, it was noted that the
 rate of loss of energy of electron energy is a function
 of energy and of some least function of the kinetic energy.
 However, since the rate of loss of energy is not available,
 the direct proportionality between the rate of loss of
 energy and the kinetic energy. The following equation (1) is

which

$$dE/dt = -k E^2 \quad (1)$$

where E is the energy of the electron
 in e.v.

It is the energy of the electron
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and the rate of loss of energy
 is $dE/dt = -k E^2$

Equation (1) is the same as the equation for the rate of
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TABLE 1

Plating Base	<u>n</u>	Range	
		<u>E_{av} = 1.35</u>	<u>E_m = 3.55</u>
Gold	0.130	0.31 mm	0.99 mm
Copper	0.048	0.67 mm	2.15 mm
Aluminum	0.021	2.21 mm	7.13 mm
Beryllium	0.006	3.29 mm	11.10 mm

From the above values of n , it is readily seen that beryllium is by far the best plating base for use in attempting to reduce the X-radiation field around a beta applicator. It is unfortunate that the sources did not arrive from ORNL in sufficient time, or with sufficient accompanying information, to permit verification of this statement with adequate experimental evidence.

This system contains a gamma-ray source. Allowances must, therefore, be made for this electromagnetic radiation as well as for Bremsstrahlung. As pointed out in the introductory material, the patient undergoing treatment is exposed only for the period of the treatment, and need not be considered in the long-term radiation-exposure picture. Therefore, in computing the gamma-ray intensity about one of these sources, dose rates will be figured as pertaining to the physician, who, in general, will be in close proximity to the patient only while actually fastening an applicator to the patient's person. Since he will be some distance away (at least arm's length) for the remainder of the treatment, the

Element	Conc. 1.0%	Conc. 2.0%	Conc. 3.0%
Gold	0.10	0.11	0.12
Copper	0.08	0.09	0.10
Aluminum	0.05	0.06	0.07
Platinum	0.03	0.04	0.05

From the above values of R , it is readily seen that position is by the best fitting curve for use in calculating the values of the radiation field around a point applicator. It is noteworthy that the curves did not agree even only in certain cases, or also indicated unexpected information to verify values of this element with adequate experimental evidence.

This system involves a point-ray source. Aluminum was, therefore, made for this characteristic radiation as well as for the treatment. It is noted that in the foregoing material, the patient's treatment is exposed only for the period of the treatment, and need not be considered in the long-term radiation-exposure system. Therefore, in computing the point-ray intensity about the point source, the value of R is given as indicated in the table, and, in general, will be in close proximity to the patient's body which is usually treated as a point source in the patient's system. There is still a small distance away (at least one inch) for the treatment of the treatment, the

applicator may be considered to function as a point source.

Computations may, therefore, be made by the use of the following equation⁽²⁸⁾:

$$\text{Eq 7} \quad R/\text{hr/mC} = \frac{6 (E/\text{photon})(\text{photons/sec})(\text{sec/hr})}{(\text{ev/ion pair})(\text{ion pair/R/cc})(4\pi R^2)}$$

Computing the dose rate at one meter from a Ra-226 source, one must take into account the three different gamma-ray energies involved. Eq 7 then becomes:

$$\begin{aligned} R/\text{hr/mC at 1 m} &= \frac{(3.6 \times 10^{-5})(3.7 \times 10^7)(3600)10^6}{(32.5)(2.08 \times 10^9)(4\pi 10^4)} (g_1 E_1 + g_2 E_2 + g_3 E_3) \\ &= 0.127 \times 10^{-3} \end{aligned}$$

where, g_1 = fraction of transitions by a given path

E_1 = energy of the emitted photon by the given path

$$g_1 E_1 + g_2 E_2 + g_3 E_3 = 0.17 \times 0.51 + 0.17 \times 0.73 + 0.01 \times 1.25$$

Beta Ray Penetration Pattern in Tissue Phantom:

The data obtained by measuring depth dose as a function of surface dose are presented in Figures 7, 8, and 9.

Figure 7 includes the axial depth-dose data obtained from Source 2 (in the Al holder) by ion chamber measurement, a curve for a Sr 90 applicator⁽¹⁶⁾ for comparison purposes, and photodensitometric readings from the autoradiographs (Figure 11). It may be seen that the Sr 90 applicator field falls to 50% of its surface intensity at 0.8 mm penetration into a water phantom, at which distance the intensity of the Ra 106 applicator field remains in excess of 100%. Theoretical concepts indicate that a

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It is noted that the information is provided in the form of a summary of the information received from the various sources and is not intended to be a complete and exhaustive statement of the information received from the various sources.

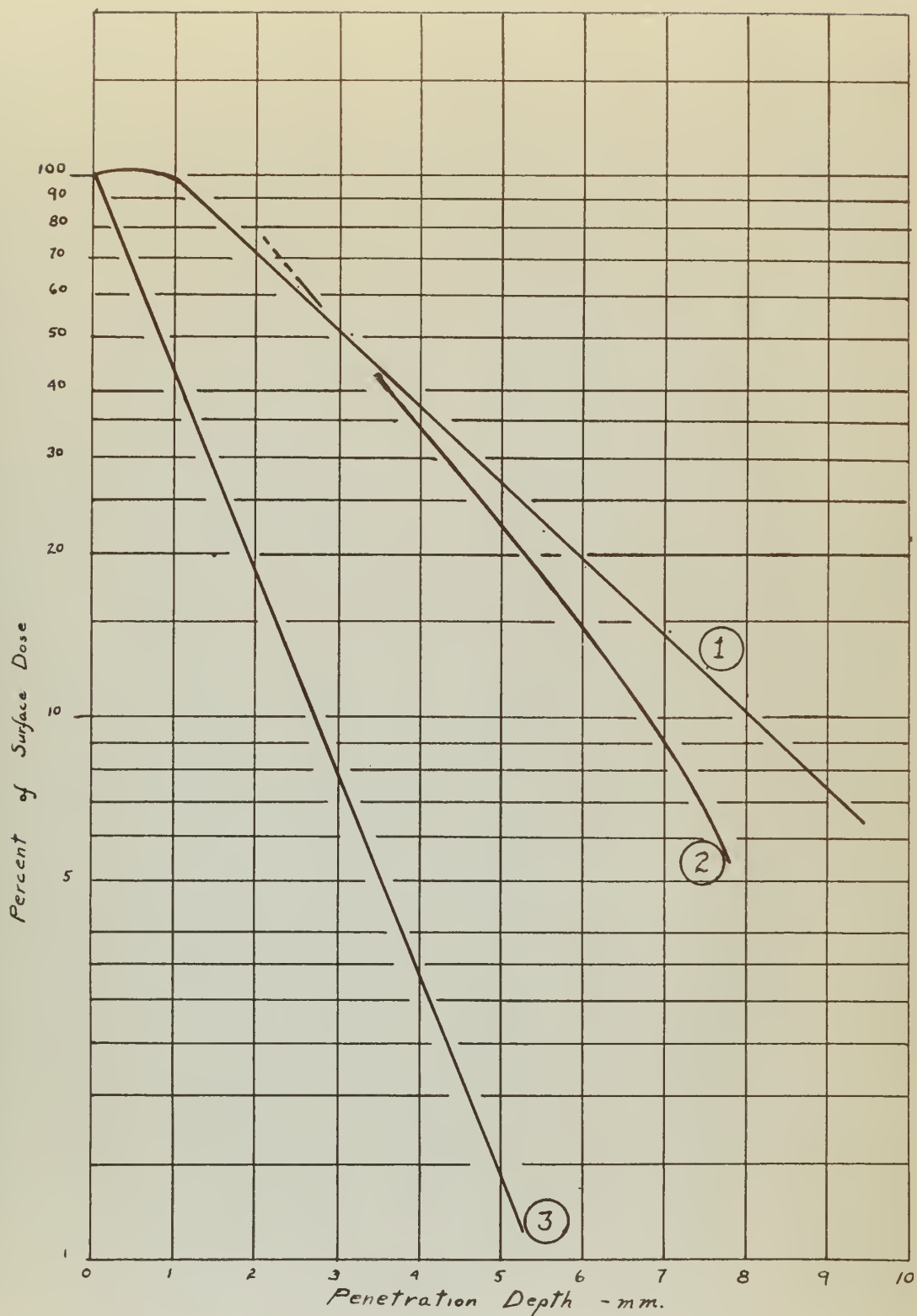


FIG 7 : Depth Dose Curves in Water Phantom
 ① Ru^{106} Test Applicator (ION CHAMBER)
 ② Photodensitometric Data on Ru^{106} Applicator
 ③ Sr^{90} Applicator

similar plateau should appear for the Sr 90 applicator. However, in medical practice, it is necessary to filter the 0.63 Mev particle emitted by the Sr 90 since it will produce an undesirable necrotic condition at the tissue surface while the therapeutically effective 2.2 Mev particle from Y 90 is delivering the desired depth dose. This condition does not exist in the Ru-Rh system, since the Ru 106 particle is of such low energy. It is also notable that at a depth of 5 mm, the Sr 90 dose rate is less than 2% of the surface dose while that from Ru 106-Rh 106 sources is still 26% of the surface rate. Thus, it may be seen that the use of Sr 90 applicators entails thirteen times the total surface dose of a Ru 106-Rh 106 applicator to produce the same dose at 5 mm depth, with a proportionately more severe surface necrosis.

The family of curves in Figure 8 represents the gradation of depth dose as measurements are made laterally across the face of the test applicator. The axial contact reading is used as the 100% reference. The beta ray beam appears to be quite well collimated by the 0.7-mm aluminum lip of the container structure, since the intensity beyond the limits of the exposed emitting surface does not exceed a small fraction of the intensity of that portion of the field to be used in therapy. However, for long exposures, additional collimation may be desirable as evidenced by the autoradiographs shown in Figure 12. This requirement would, of course, be adjusted to the type of tumor growth or other lesion to be irradiated, since

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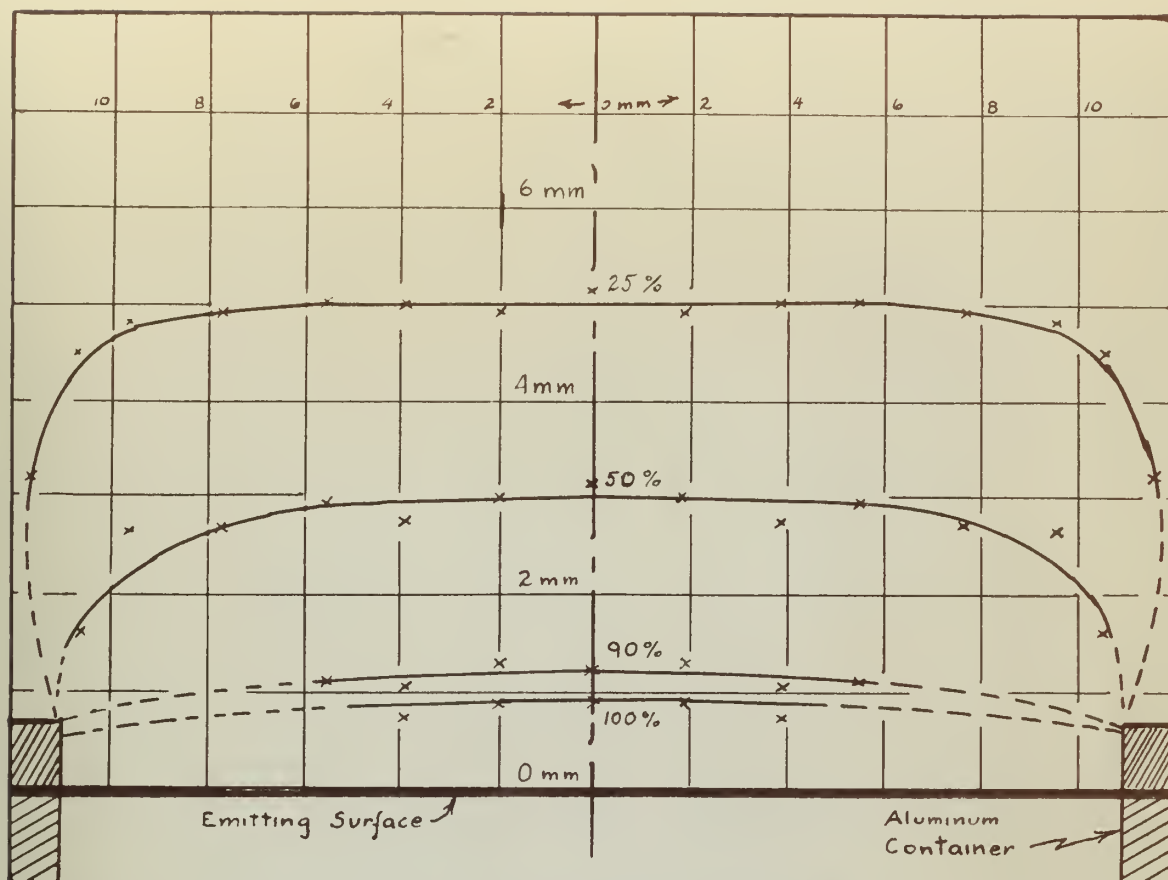


Fig 8: Isodose Curves around Ru^{106} Applicator Immersed in Water

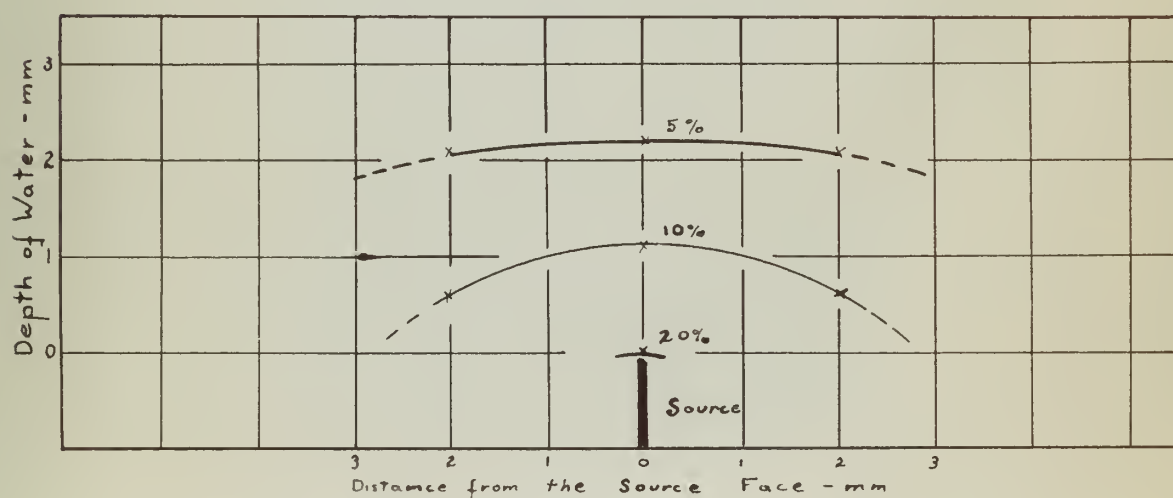


Fig 9: Isodose Pattern at the Edge of Source 2 Immersed in Water. Percentages are of the axial contact reading

some cases may require a rather high total dose at all the fringes and on into the surrounding skin. In measuring these isodose patterns, readings were taken along a single radius line in order to present the conditions which would prevail if the source had been properly plated. The curves shown are for a completely immersed source. Tissue may not fill the recess in the applicator face in actual practice. The isodose pattern could then be applied from the tissue surface rather than the emitting surface, and would, therefore, give a better collimating effect. Due to the physical dimensions of the ion chamber and applicator (Figures 4 and 5), it was not possible to complete a closed traverse of the 100% and 90% isodose curves in the region of the retaining lip of the applicator. No intensity in excess of 25% of the surface dose rate was noted on the surface of the applicator at a radius of 13 mm from the center, and no beta intensity was measureable at the edge, back, or side of the container. Combined gamma ray and Bremsstrahlung readings, using a Geiger-Mueller counter, (no beta) for Source 2 showed 14 mr/hr after penetration of 4 cm of tissue equivalent plastic.

Figure 9 is an isodose plot of data obtained using the ion chamber and approaching the edge of the unshielded Source 2 (no container) immersed in water. It is indicative of the relatively small amount of collimating material necessary to confine the beta particle beam to the desired limits. Even as the ion

There is no other person in the world who is so much interested in the progress of the human mind as I am. I have been thinking of you very much lately, and wondering how you are getting on. I hope you are well and happy. I have been very busy lately, but I have managed to find some time to write to you. I have been thinking of you very much lately, and wondering how you are getting on. I hope you are well and happy. I have been very busy lately, but I have managed to find some time to write to you.

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chamber approached so close to the edge of the disc that appreciable radiation could enter directly from either face of the disc, the intensity did not exceed 20% of the axial reading. Since the geometry was so unsatisfactory in the measurements involved here, it is safe to say that the true gradient and maximum value is much more favorable than indicated.

Autoradiographs:

The autoradiographs shown in Figures 10, 11, and 12 were prepared in confirmation of the information obtained by electronic measurement.

Figure 10 was obtained by laying the applicator holder, with Source 2 in place, on its side on a strip of X-ray film. It serves to demonstrate that no particulate emission is observed from the sides of the container. The apparent curvature of the edge is due to the geometry of a circular source standing on edge on a flat plate. The apparent fringing is also due to this geometrical distortion.



Figure 10. Applicator placed on its side on X-ray film to demonstrate sharp cutoff of radiation field at applicator surface. Exposure = 5 sec. Source 2.

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Figure 11. This is a portion of a series of autoradiographs obtained by stacking X-ray film in front of the applicator. It demonstrates the variation in depth doses: Exposure = 1 sec. Source 2.



a. Contact



b. 5 layers of film
0.156 gm/sq cm



c. 10 layers of film
0.312 gm/sq cm



d. 15 layers of film
0.468 gm/sq cm

This is a report of a study of the effects of the use of the word "and" in the title of a paper. The study was conducted by the author and the results are presented in the following table. The study was conducted in the year 1960.

   	   
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Figure 11. (continued)



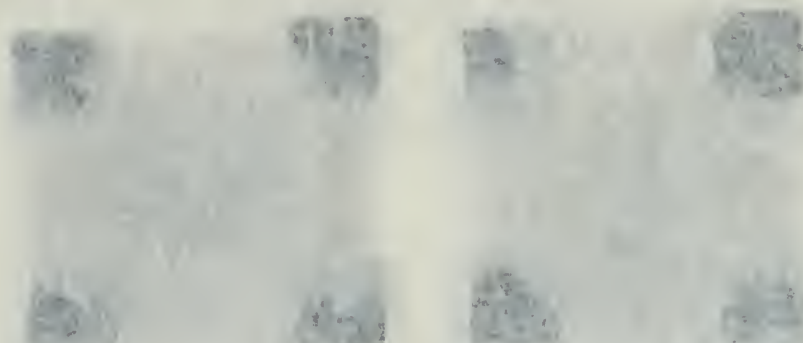
e. 20 layers of film
0.624 gm/sq cm



f. 25 layers of film
0.780 gm/sq cm



g. 30 layers of film
0.936 gm/sq cm



1900-1901 (continued)

1900-1901 (continued)



1900-1901 (continued)

Figure 12. Edge of X-ray film exposed to beta-ray field from applicator. Demonstrates the outline of the radiation field. Exposures = 5 and 20 sec. Source 2.



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Figure 11 is a portion of the series of autoradiographs obtained by stacking X-ray film and permitting the beta ray beam from Source 2 (in holder) to penetrate through the pile. Densitometric data are shown in Figure 7. The contact exposure shows the rather slight fringing at the edge of the applicator which can be greatly reduced by additional collimation.

Figure 12 is an edge exposure and is, in effect, a photographic reproduction of Figure 8. This was greatly overexposed in order to demonstrate the outline of the entire beta field.

Biological Observations:

The observations included here are presented in diary form for convenience of interpretation. Elapsed time is computed from the time at which the applicator, containing Source 2, was mounted on the test animal.

Date and Time of Observation	Elapsed time	Observations and Comments
1540, 25 April		Applied source to the shaved nape of rabbit's neck with adhesive tape. No breaks in the skin were observable.
0720, 26 April	15:40	No observable effect at removal of applicator.
1600, 27 April	48:20	Definite erythema existed over an area the size and shape of a kidney bean, corresponding to the more active portion of the applicator (see Fig. 2). The coloration was about that of a moderately severe sunburn.

0815, 28 April	64:35	Complete erythema existed over an area 22 mm in diameter. The entire area was of the same color previously observed, except that the area noted 27 April had become a deep magenta and portions thereof had become necrotic. There was no discoloration observable outside an area equivalent to the exposed emitting material of the applicator.
0815, 30 April	112:35	Severe necrosis was evident over the entire area, with some sloughing in the area corresponding to the more densely plated portion of the source.
1245, 1 May	141:05	The necrotic area appeared generally the same, with the addition of two open lesions approximately 1 mm in diameter, which were present in the most intensely irradiated area. A mild erythema had appeared in a band about 1 mm wide surrounding the necrotic area, apparently due to the low intensity fringing noted in Figure 8.
1300, 3 May	189:20	The entire area appeared the same as on 1 May, with some additional loss of skin near the edges of the necrotic area, and in the spots previously noted.
1300, 5 May	213:20	No apparent change.
0900, 12 May	377:20	No further sloughing of skin was observed. The necrotic area was the same size. The erythematous area noted on 1 May appeared to have returned to normal. The hair surrounding the necrotic area had grown 1/8 to 1/4 inch. There was no apparent hair growth in the injured area, nor was there any observable epilation.

At all times during these observations, the animal appeared to be otherwise completely normal.

From the observation of this test animal, it is apparent that any radiation damage to tissue subjected to irradiation by a

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Supplement: Letter to all, 2007, <http://www.ck12.org/ck12/letter-to-all>, accessed 12/16/06

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Ku-Rh applicator of this type is confined to the area immediately adjacent to the emitting surface, and that any fringing effects are of limited severity and heal rapidly.

No histological sections were studied in a limited test of this nature. They should, however, certainly be included in the extensive animal studies which must be done before this beta-ray applicator may receive any extensive clinical use.

which consists of this form is confined to the case immediately

arising at the meeting referred to, and that any further action

may be taken at a later date.

No financial statement need be submitted in this form.

Of this nature. They should, however, be submitted in

the appropriate cases where they are required to be submitted.

For application see form and instructions attached.

CONCLUSIONS

Consideration of the isodose and penetration intensity curves for soft tissue, obtained in this study, shows a Ru 106, Rh 106 applicator to be very satisfactory for use in radiation therapy.

Properly collimated, the high-energy beta particles supplied by Rh 106 provide a strong radiation field to a depth of more than 5 mm. Use of this isotope does not entail heavy surface necrosis due to a low-energy beta particle from the parent Ru 106, nor does it require appreciable attenuation of the usable beam to filter out low-energy particles. Thus, for treatment of surface lesions to a depth of several millimeters, an adequate field can be established without the introduction of other pathological conditions. For treatment of superficial surface conditions, such as fungus infections, the 0.9-mm 100% dose-rate region permits high-intensity, surface irradiation without causing extensive damage to the underlying tissue.

Proper collimation of the beta-ray beam to suit the therapeutic problem can readily be obtained by variation of the mechanical structure of the applicator holder.

Although gamma radiation is inherent in the use of this isotope family, the intensity thereof is below established gamma-ray tolerance values for sources having beta-ray dose rates in the normal therapeutic range. The gamma-ray intensity from Rh 106 is much

lower than that from radium sources of the same beta-ray intensity. Dr. Neary⁽³⁰⁾ has compiled the ratio of the intensities of these two radiations for typical radium plaques and also the gradient of dose rate with depth. He has stated:

"The value of the beta-gamma ratio for a full-strength applicator with surface dose-rate about 5,000 r/hr is of the order of 25"

and

"The most striking feature is the very rapid fall-off of the depth dose; e.g., only about 50 per cent at 1 mm."

A similar computation for Ru 106 applicators, based on the values obtained herein (see Preparation of Applicator) shows:

$$\begin{aligned} \text{beta/gamma } \frac{0.715}{0.127 \times 10^{-3}} &= \frac{\text{beta dose rate/mC}}{\text{gamma dose rate/mC}} \\ &= 5.63 \times 10^3 \text{ for Ru 106, Rh 106.} \end{aligned}$$

It is readily seen that, from the point of penetration of beta particles, Ru 106 is greatly superior to both radium and Sr 90 applicators as currently prepared, and has a beta-gamma ratio advantage over radium by a factor of 210. It is believed that the advantages of the Ru 106 beta-ray penetration pattern are so superior to those of Sr 90 that the low gamma-ray intensity which is introduced may be tolerated, especially in view of the intensity currently tolerated in the use of radium.

Ru 106 is also superior to radium in that no gas-leakage hazard exists.

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Bremsstrahlung can be materially reduced by employment of plating bases and containers of low atomic number elements. Of the lower atomic number materials, beryllium is the most satisfactory in that it is a light, strong solid, and is not nearly so chemically active as some of its neighbors in the periodic table. Its toxic effects can be readily prevented by proper handling.

The half life of $Ra\ 106$ is long enough that an applicator constructed thereof has an output of sufficient constancy for normal therapeutic use. A simple decay curve based on its initial calibration value is adequate to determine the dose rate at the start of a treatment. Such a small portion of one half-life transpires during the few hours of a treatment period as to permit the assumption of constancy of output for the period in question.

Examination of the limited available biological data described indicates the true tissue effect to be as predicted by the measurements in the tissue phantom and by the autoradiographs.

It is suggested that the following be included in the report:

The first part of the book is devoted to a general survey of the history of the book, and the second part to a detailed study of the book's content. The book is written in a clear and concise style, and is well illustrated with numerous examples and diagrams. It is a valuable reference work for anyone interested in the history of the book, and is also a useful text for students of the subject.

the manuscript in the library should not be the only one.

SUMMARY

The problem of the depth-dosage distribution due to beta particle irradiation from sources of Ru 106 in equilibrium with Rh 106 is studied in terms of ionisation-chamber measurements in a tissue-equivalent, water phantom.

The equipment and methods employed are described in detail for the assistance of those who may do further studies of this sort.

Auxiliary data are provided by autoradiographic studies using the various sources available.

Calculations are shown to be in accord with the available experimental data on the sources studied. The results of the calculations and experimental data demonstrate Ru 106 applicators to be practicable sources of high-energy beta rays for use in radiation therapy. The electromagnetic radiation involved in its use is small and may be further minimized by use of structural materials of low atomic number. The fall off of beta-ray dose rate with tissue depth provides a region of 0.9-mm depth at 100% of the surface dose rate, and a logarithmic decline from 0.9 mm to 25% at 5 mm.

Examination of limited biological evidence confirmed the anticipated results as to area affected and depth of tissue reaction.

RESULTS

The results of the first series of experiments are shown in Table I.

These results show that the rate of reaction is proportional to the

concentration of the reactants in the range of concentrations studied.

A plot of $\log k$ versus $\log [\text{A}]$ gives a straight line with a slope of 1.

The activation energy for this reaction was calculated to be

12.5 kcal/mole. This value is in good agreement with the value of

13.0 kcal/mole.

These results are in good agreement with the results of the

second series of experiments.

The results of the second series of experiments are shown in Table II.

These results show that the rate of reaction is proportional to the

concentration of the reactants in the range of concentrations studied.

A plot of $\log k$ versus $\log [\text{A}]$ gives a straight line with a slope of 1.

The activation energy for this reaction was calculated to be

12.5 kcal/mole. This value is in good agreement with the value of

13.0 kcal/mole. The rate of reaction does not vary with

the concentration of the products in the range of concentrations studied.

These results are in good agreement with the results of the

third series of experiments.

The results of the third series of experiments are shown in Table III.

SUGGESTIONS FOR FURTHER STUDY

Ru 106 beta-ray sources have been shown to be physically acceptable for therapeutic use. Initial biological checks have confirmed the physical studies. Before this radioactive element may be placed in general clinical use, additional biological studies must be performed and analyzed, both as to the effectiveness of this type of applicator on normal tissue and on tumor tissue. In view of the failure of the beryllium-based source to arrive in time for study, this work must also be carried out. Additional design work must be done with respect to applicator shape and materials.

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Das Journal wird zweimal im Jahr veröffentlicht. Jede Ausgabe enthält eine Reihe von Aufsätzen, die von renommierten Autoren verfasst wurden. Die Themen der Aufsätze sind vielfältig und reichen von der Geschichte der Philosophie bis hin zu aktuellen Fragen der Philosophie.

Das weitere Vorgehen besteht darin, die resultierende Lösung zu verifizieren, d.h. zu überprüfen, ob sie die ursprüngliche Aufgabe erfüllt.

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of evidence as shown in Table 1. In view of the

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Source: *Journal of the American Statistical Association*, 1997, 92, 103-114.

of these will be found in the following table:

A P P E N D I X I

APPENDIX

CONTENTS OF THE APPENDIX

The following tables contain the results of the experiments conducted by the author in the laboratory of the University of California, Berkeley, during the summer of 1907. The tables are arranged in the order in which the experiments were conducted, and each table is preceded by a brief description of the experiment. The tables are arranged in the order in which the experiments were conducted, and each table is preceded by a brief description of the experiment.

I. EXPERIMENT

1

APPENDIX I

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